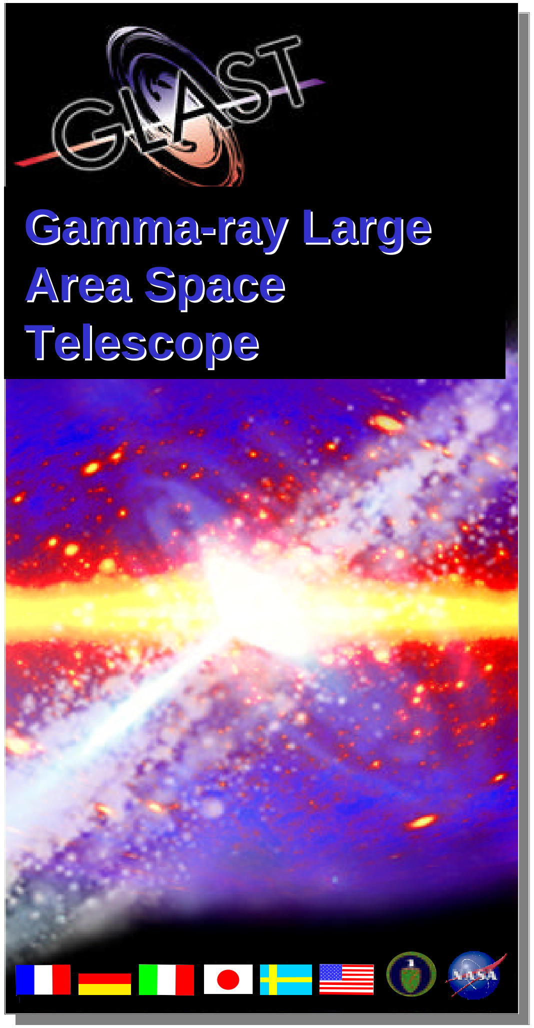

Crystal Detector Element (CDE) Manufacturing Readiness Review

Manufacturing and Test Requirements

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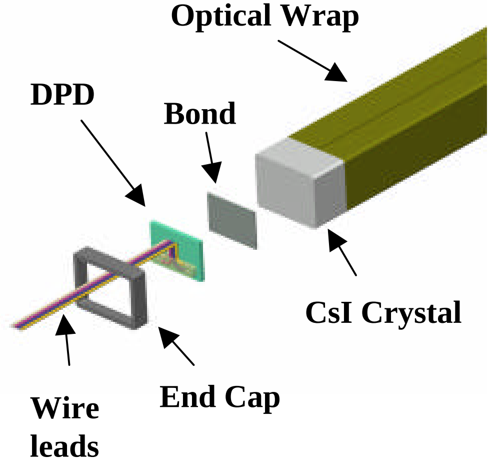
Outline

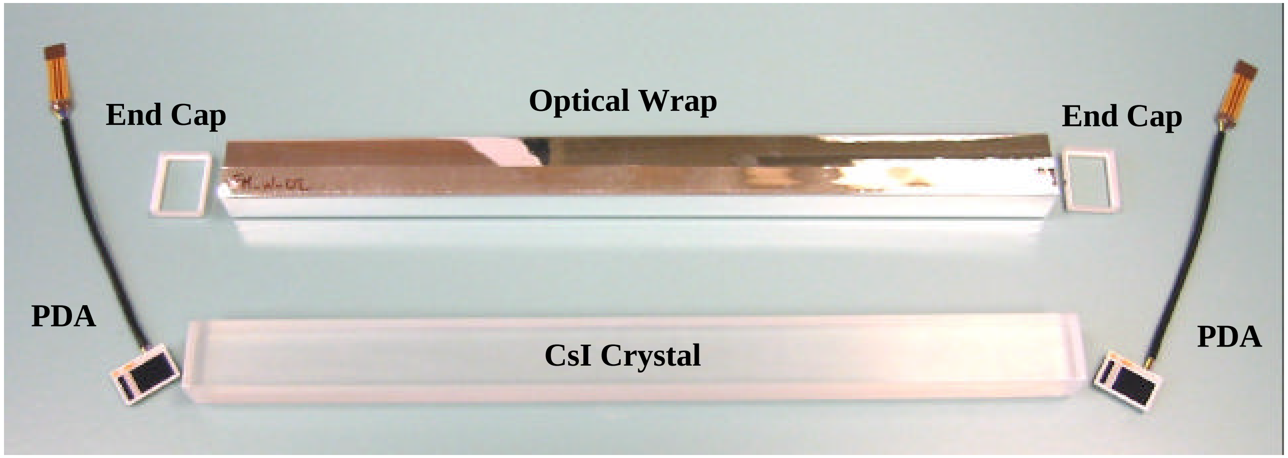
- **Manufacturing and Test Requirements**
  - Design concept and drivers
  - Development program
  - Requirements
  - Qualification plan
  - Acceptance test plan

CDE Design Components

- CDE has four components
  1. CsI(Tl) crystal
  2. Two PhotoDiode Assemblies (PDAs)
     - Hamamatsu S8576 Dual PhotoDiode (DPD)
     - Wire leads, soldered and staked
  3. Wrapper
     - 3M Visual Mirror VM2000 film
  4. Two machined end caps



EM CDE prior to assembly



CDE Design Drivers

Design Feature	Design Driver
CsI(Tl) crystal	Active calorimeter over broad dynamic range Low energy threshold High stopping power for EM showers
Crystal surface treatment (light taper)	Position sensitivity Reliable energy measurement
Photodiode readout	Low-power, low-mass, small, reliable readout High light yield (= low E threshold) with CsI(Tl)
Two dual photodiodes	Large dynamic range Redundancy for energy measurement Position measurement
VM2000 wrapper	High light yield (= low E threshold) Stable wrap, easy to handle
End caps	Stable attachment within cell

Development program

- History of CDE development at NRL
  - 1996 Calorimeter: 25 "CDEs"
    - Meltmount optical wax for diode bond
      - Good adhesion, but not optimally clear and not thermally stable
  - 1998 Calorimeter: 80 "CDEs"
    - Epotek 301 optical hard epoxy
      - Excellent clarity, but extremely poor thermal stability
    - Tetratex (Teflon) + aluminized Mylar optical wrap
      - Excellent whiteness, but questions about longevity
  - Status as of Christmas 1998
    - Optical bonding was a disaster, needed something flexible
    - Xtal wrapping was fine, but maybe there are brighter wraps

Development program

- History of CDE development at NRL
  - 2000 to 2002 bonding studies
    - More than 300 bonds using
      - Six soft epoxies (MasterBond) and silicone encapsulants (Sylgard, DC)
      - Two silicone primers
      - Three bonding methods (with many variants)
    - Conclusion: silicone (DC 93-500) and primer (DC 92-023) with bond volume defined by mold
  - 2002 Engineering Model Calorimeter: 96 CDEs
    - Joint with Swales, ~50 practice bonds during mold development
    - Conclusion: molding process for VM2000 optical wrap defined
  - 2003 flight risk reduction program with Swales Aerospace Products
    - >100 practice bonds during mold development

Development program

- Lessons learned
  - Optical performance is *the* crucial test
    - A bond can be mechanically strong and show no obvious visual evidence of separation, at the same time that it has optically failed!
      - Visual inspection is good, but not good enough
    - Therefore: test of scintillation light yield is included in both
      - Bond process Qualification plan
      - Acceptance test plan on 100% of CDEs
  - Stability of optical bond against thermal cycling
    - CTE mismatch can cause optical failure
      - Optical failure in CDE drops light yield by 30–50%
        - » Failures are easy to detect!
      - Optical failure evident before 10 cycles
    - Therefore: thermal cycling test is included in Qual plan

CDE Requirements

- Controlling document
  - LAT-SS-00133-03: "Flight Crystal Detector Element Specification"
- Verification and test documents
  - LAT-DS-01900-01: "Crystal Detector Element" drawing
  - LAT-SS-02236-02: "Flight CDE Qualification Plan"
  - LAT-SS-02235-03: "Flight CDE Acceptance Test Plan"
- Procedure documents (details to follow)
  - CDE assembly (bonding, wrapping, capping)
  - Testing (bond strength, optical performance)

- Documents are released and configured

CDE Requirements

- Mechanical requirements (from LAT-SS-01133-03)
  - Dimensional
    - Driver: assembled CDE must fit securely within rigid cell of the CAL carbon-composite mechanical structure

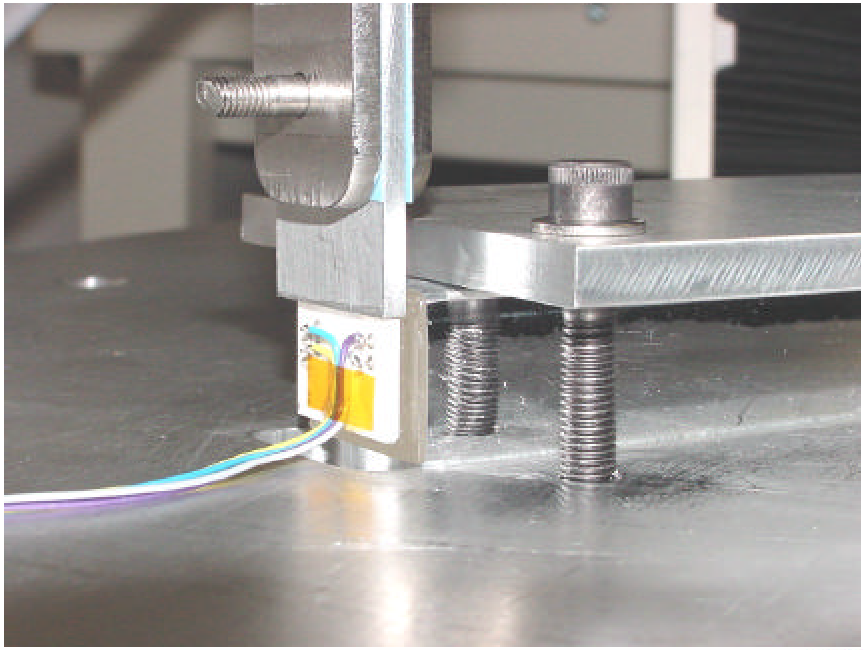
Parameter	Minimum Value (mm)	Maximum Value (mm)
CDE Total Length	NA	336.3
CDE Cap-to-Cap Length	330.8	331.6
CDE Envelope Height	NA	20.4
CDE Envelope Width	NA	27.2
Bondline thickness	0.8	1.0
PDA Height Location	2.40	3.40
PDA Width Location	2.15	3.15
Wrapper Skewness	NA	0.7

CDE Requirements

- Mechanical requirements (from LAT-SS-01133-03)
  - Bond strength and thermal stability
    - Driver: CTE mismatch between PDA and xtal causes stress in bond
      - Hard epoxies fail; silicones (without primer) don’t adhere
      - Need soft, flexible bond with strong adhesion
      - Solution: Silicone elastomer with primer. Bond laid up in mold that defines geometry.
    - To test:
      - Shear strength
      - Stability of optical bond against thermal cycling

CDE Requirements

- **Mechanical: Bond strength**
  - Shear to failure with calibrated load cell
  - Requirement
    - Derived from differential expansion over –30C to +60C
    - Shear strength shall exceed 9 lbf
  - Test procedure
    - LAT-PS-02572-01



Shear test underway on Risk-Reduction CDE at Swales

CDE Requirements

- **Mechanical: Thermal cycling**
  - **Optical performance measured before and after 25 thermal cycles (50 cycles for Qual)**
    - **Loss of >20% of light shall be deemed a failure**
    - **Recall development program result:**
      - **Optical failure causes loss of about half of light**
      - **Failure evident in <10 cycles**
    - **Optical test in accordance with LAT-PS-02571-01**
  - **Thermal profile**
    - **–30C to +60C range, ±20C per hour ramp**
    - **1 hr soak at min and max temperatures**

CDE Requirements

- Optical performance (from LAT-SS-01133-03)
  - Driver: output signal amplitude must match electronics design
    - Scintillation light yield
  - Driver: science requirement for gamma-ray imaging
    - Position dependence of light yield
      - Instrinsic to xtal, but could be modified or ruined by failure in CDE assembly processes

Parameter	Minimum Value	Maximum Value
Light yield, large PIN (e/MeV)	6500	NA
Light yield, small PIN (e/MeV)	1100	NA
Light yield ratio	5	7
Light asymmetry change	0.25	0.70
Light taper	0.45	0.75
End-to-end light yield ratio	0.87	1.15
Muon energy resolution (rms)	NA	8%

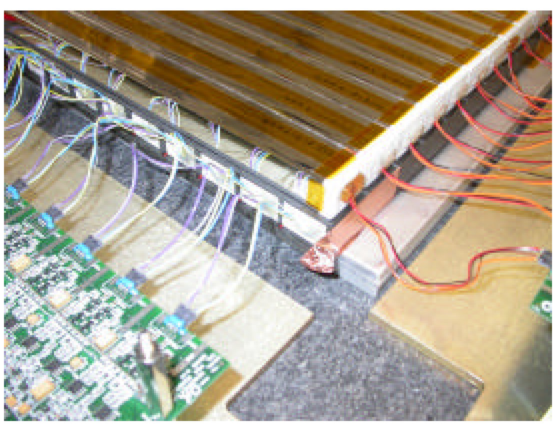
CDE Requirements

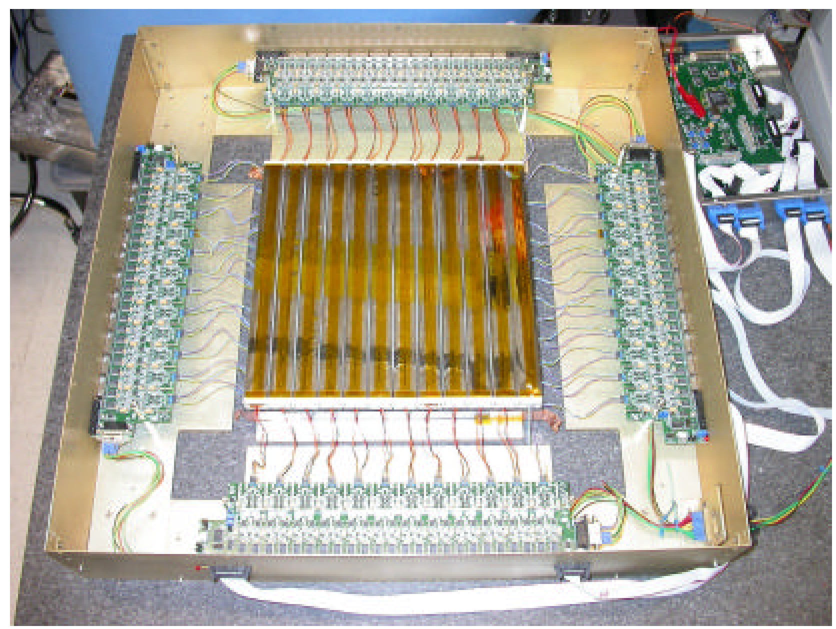
- **Optical performance (from LAT-SS-01133-03)**
  - To test: measure optical performance of CDE batch with muon telescope
  - LAT-PS-02571-01: "CDE Optical Test Procedure"
    - Muon telescope in use at NRL, will transfer to Swales
    - Swales training week of 3 Nov
    - Doc will be revised, released after training
  - Muon telescope needs to be useable by non-physicists
    - Needs to be turn-key device
    - Needs to have straightforward test reports
    - NRL will provide expert support if service is necessary

Optical Test Equipment

- CDE Muon Telescope
  - CDEs are tested in lots of 12
  - Cosmic ray muons are imaged in array of 12 reference CDEs, and maps of light yield as a fcn of position are generated for 12 CDEs under test
  - Test duration is nom. 12 hours (~1 muon per CDE per sec)

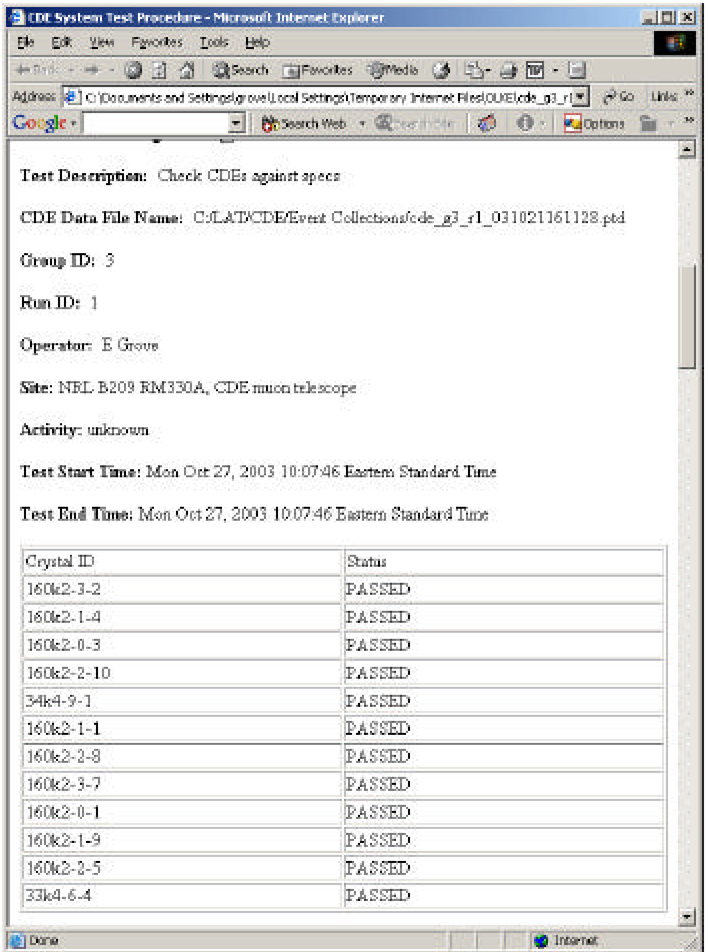
Pre-Qual CDEs in Muon Telescope





CDE Muon Telescope

❑ Sample test report


CDE System Test Procedure - Microsoft Internet Explorer

Test Description: Check CDEs against specs

CDE Data File Name: C:/LAT/CDE/Event Collections/cde_g3_r1_031021161128.ptd

Group ID: 3

Run ID: 1

Operator: E Grove

Site: NRL B209 RM330A, CDE muon telescope

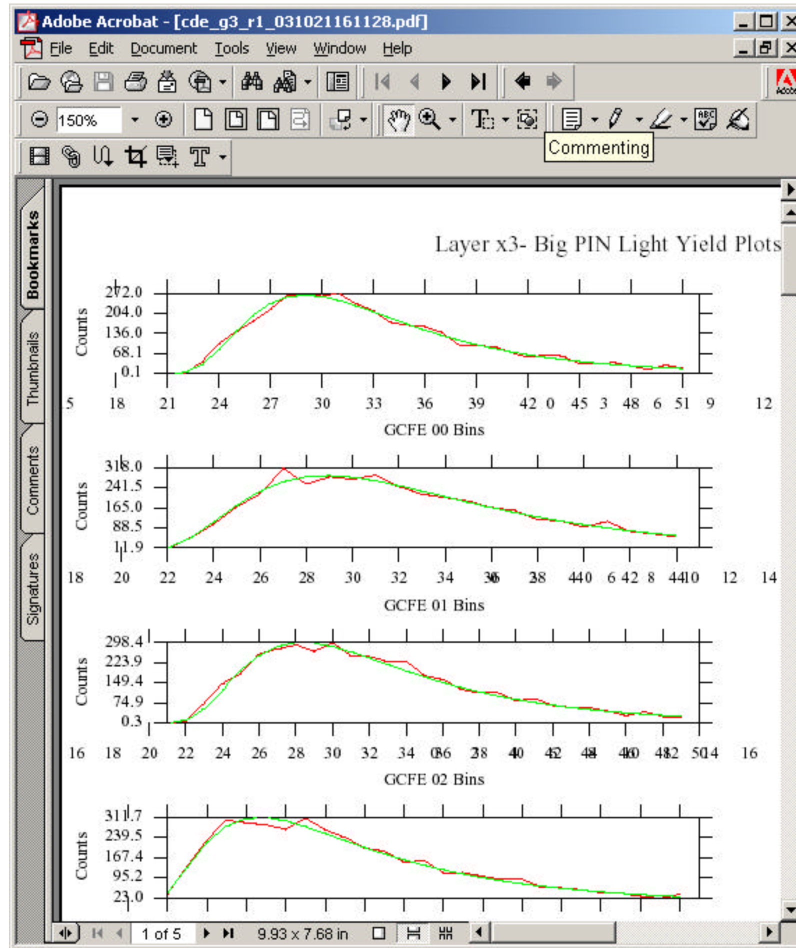
Activity: unknown

Test Start Time: Mon Oct 27, 2003 10:07:46 Eastern Standard Time

Test End Time: Mon Oct 27, 2003 10:07:46 Eastern Standard Time

Crystal ID	Status
160k2-3-2	PASSED
160k2-1-4	PASSED
160k2-0-3	PASSED
160k2-2-10	PASSED
34k4-9-1	PASSED
160k2-1-1	PASSED
160k2-2-8	PASSED
160k2-3-7	PASSED
160k2-0-1	PASSED
160k2-1-9	PASSED
160k2-2-5	PASSED
33k4-6-4	PASSED

❑ Sample test plots



Qualification Plan

- **Controlling document**
  - **LAT-SS-02236-02: "Flight CDE Qualification Plan"**
- **Qual program will be performed on 12 CDEs**
  - **Six steps performed in sequence**
  - **Practice with 12 pre-Qual CDEs is now in Step 4**

Step	Qualification test	Qualification CDE number											
		01	02	03	04	05	06	07	08	09	10	11	12
1	Visual inspection	X	X	X	X	X	X	X	X	X	X	X	X
2	Mechanical	X	X	X	X	X	X	X	X	X	X	X	X
3	Optical	X	X	X	X	X	X	X	X	X	X	X	X
4	Thermal cycle	X	X	X	X	X	X	X	X				
5	Rise to altitude										X		
6	Bond strength					X	X	X	X	X	X		

Pre-Qual CDEs

- Pre-Qualification CDEs are currently under test
  - 12 CDEs assembled
  - Materials
    - Proto-flight CsI(Tl) crystal (identical to flight)
    - Proto-flight PDAs (flight rejects)
    - EM end caps (non-flight material and machinist)
    - Flight wrapper (flight lot)
  - Tooling
    - Same bonding tooling as for Qual
  - NCRs during assembly
    - S/N 160K2-2-10: visible delamination on corner of one bond
    - S/N 160K2-0-5: evidence for delamination during removal of mold
    - Corrective action
      - Mask removal procedure has been modified

Pre-Qual CDEs

- Thermal cycle test results
  - 8 CDEs have completed 12 thermal cycles
  - Current light yield is within 3% of initial light yield
    - No evidence for optical failure from cycling
    - Recall: failure should be evident before 10 cycles
  - Thermal cycling continues …
- Shear strength test results
  - 4 PDAs have been sheared from 2 CDEs
    - 70.3 lbf 101.8 lbf
    - 84.7 lbf 72.9 lbf
  - Exceeds spec (9 lbf) by factor of 8
  - More shear tests to come …
- Every expectation for success

Acceptance Test Plan

- CDE Acceptance Test plan mirrors Qual plan
  - Controlling document
    - LAT-SS-02235-03: "Flight CDE Acceptance Test Plan"
      - Defines test requirements, sample fraction, and test reporting
  - Test plan
    - Visual inspection
      - 100% in-process and final inspection
      - Same criteria as Qual plan
    - Mechanical inspection
      - 100% final inspection
      - Same dimensional and mass criteria as Qual plan
    - Optical performance
      - 100% final inspection
      - Same criteria as Qual plan

Acceptance Test Plan

- CDE Acceptance Test (cont.)
  - Test plan (cont.)
    - Bond strength
      - ~1% of CDEs shear tested to destruction
      - Same strength spec as Qual plan
    - Thermal stability
      - ~1% of CDEs for 25 cycles (-30C to +60C)
      - Same criterion as Qual plan

Acceptance Test Plan

- Reporting
  - Acceptance Data Package
    - "Tracking Spreadsheet"
      - Parts traceability for CDE assembly
        - » Crystal and PDA serial number
        - » Wrapper lot number
      - Link to Swales assembly Traveler
    - "Optical Test Report"
      - Electronic copy of optical test results for direct importation into CAL Assembly Database
      - Allows trending of CDE performance throughout CAL assembly
  - Certificate of Conformance
    - Conformance with assembly and test procedures
    - Signed by Swales
  - Swales Traveler from bonding, wrapping, and capping processes shall be made available to NRL on request.

Appendices

- Supporting slides
  - Additional details on Qual program
  - Thermal cycle tests during development program
  - Bond strength tests during development program
  - CsI(Tl) crystals
  - VM2000 optical wrap

Qualification elements not yet described

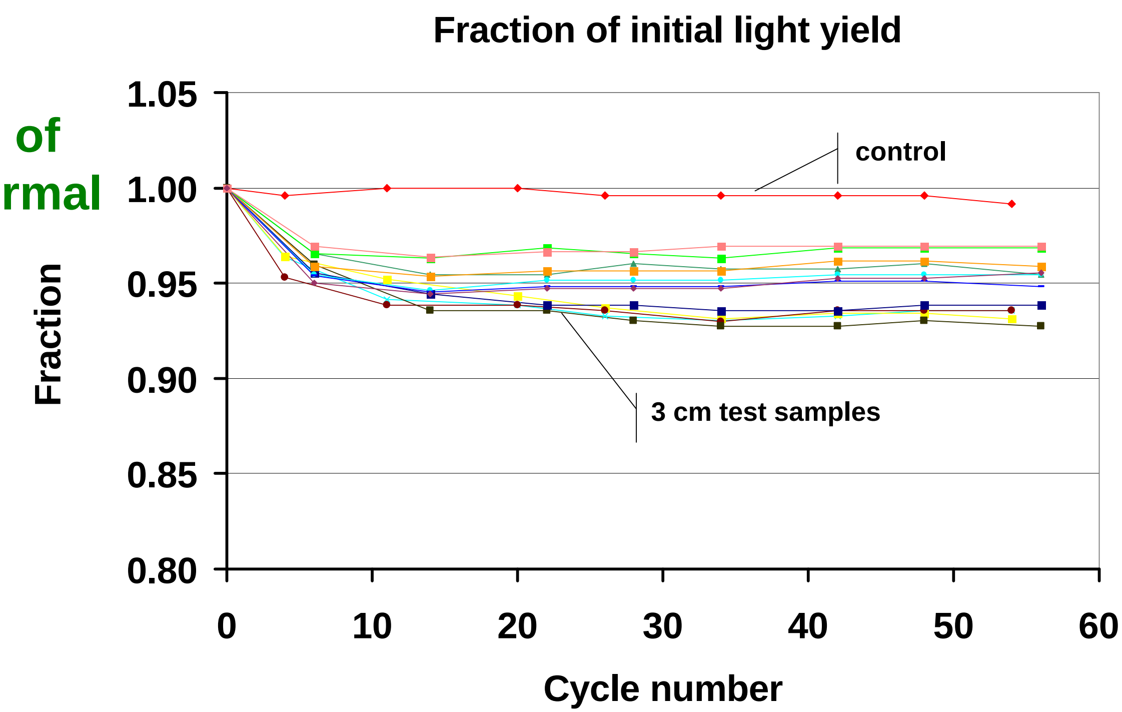
- Visual inspection
  - In-process and final inspection on all 12 Qual CDEs
  - Requirements (outlined here)

Item	Criteria
Bond	Cured, no delamination, limits on void number and size
Crystal	Limits on chips, cracks
Wrapper	Tight, square, and non-interfering
End Cap	Firmly seated

  - Process control gives tight wrap, seated cap
- Rise to altitude
  - Performed on 1 of 12 Qual CDEs
  - Optical performance measured before and after pressure drop of >0.98 atmosphere in 60 sec
    - Loss of >20% of light shall be deemed a failure
    - Optical test in accordance with LAT-PS-02571-01

Thermal Cycling

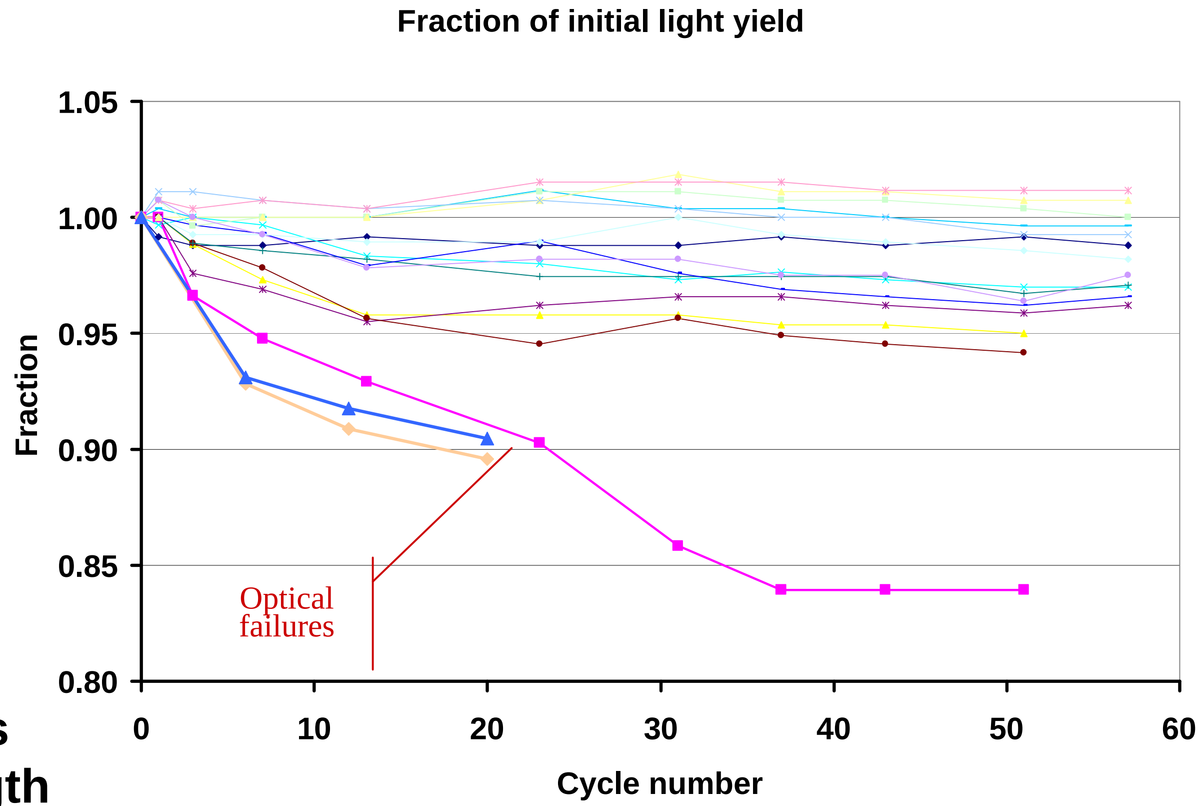
- **Optical performance of test samples under thermal cycling**
  - **Test samples are 3 x 3 x 3 cm cubes with single EM photodiode**
  - **Test samples typically decline ~5% from their initial light yields and reach plateau**
  - **Optical properties of bonds survive thermal cycling**
  - **Silicone + primer creates thermally stable bonds**



Early Thermal Cycling Tests

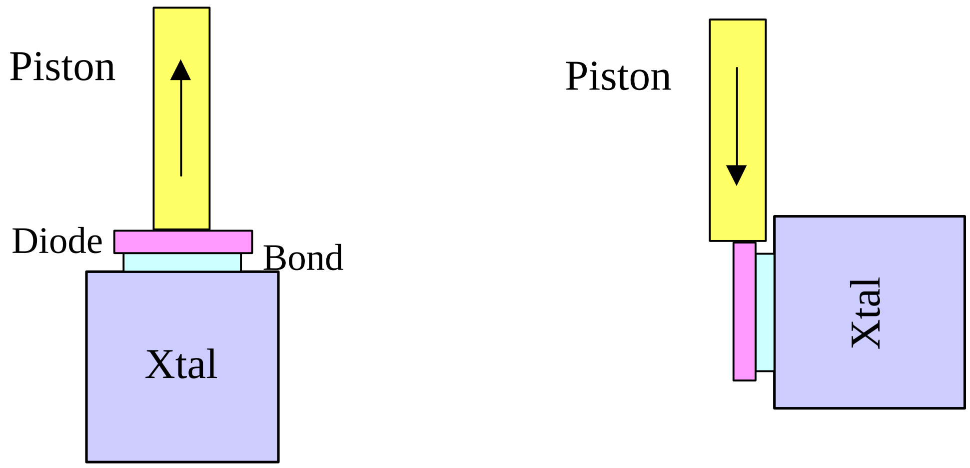
- 16 sample bonds
  - Created with several methods early in bonding study
  - 13 survive cycling
  - 3 have optical failure
- Optical failures
  - ~15% degradation in test sample is equivalent to ~50% degradation in CDE.
- We extracted samples for mechanical strength tests *after* optical failure…

Prior to creation of stable bonding process



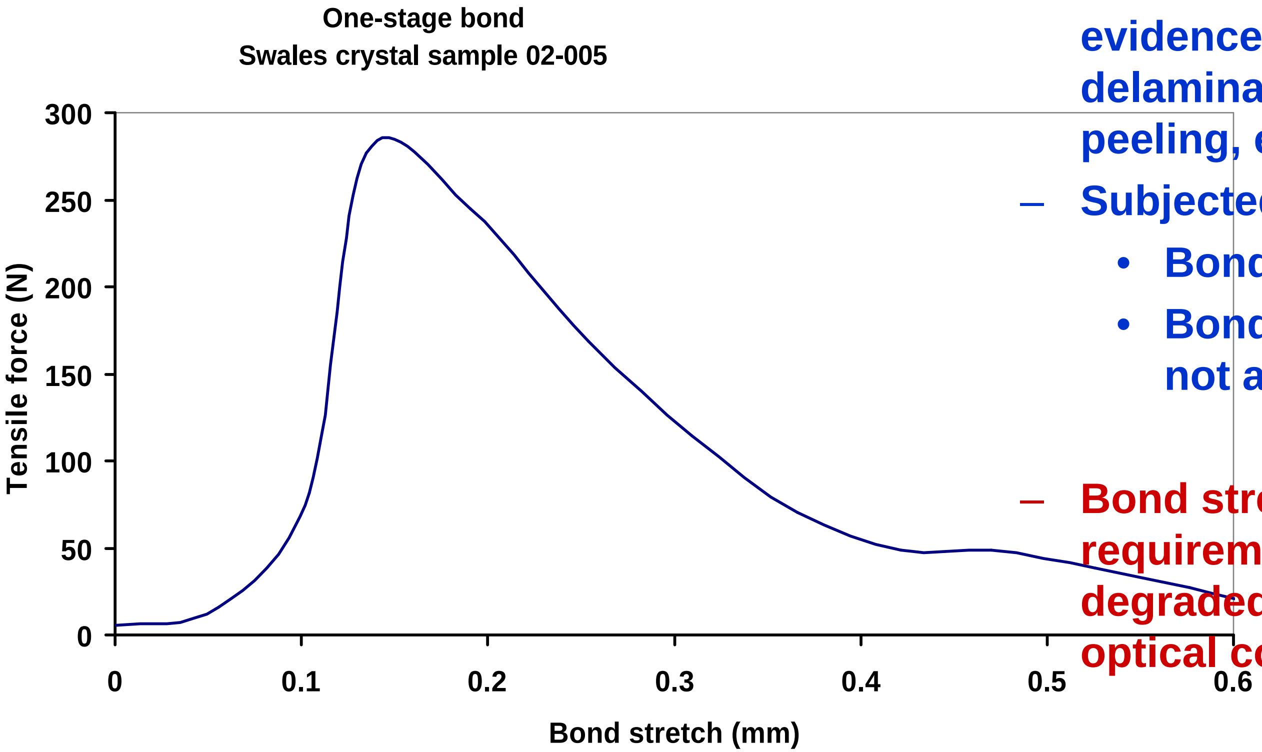
Mechanical Strength Tests

- Two types of destructive tests were performed at NRL
  - Tensile strength
    - CETIM requirement: 10 N (2.2 lbf)
  - Shear strength
    - CETIM requirement: 0.12 N/mm^2 (8 lbf » 35 N for EM DPD)
      (9 lbf » 40 N for Flight DPD)
  - >70 samples tested
- Samples were pulled or sheared to failure in Dynamic Load Test Stand

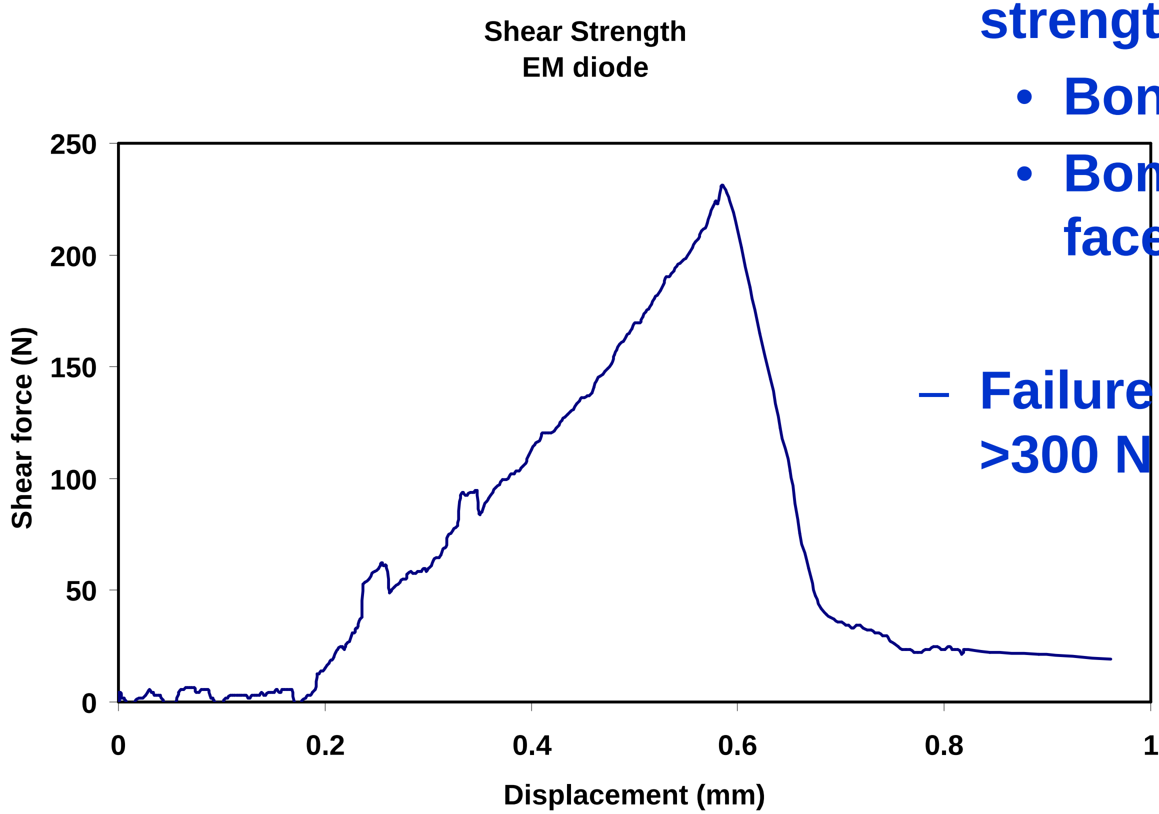


Tensile Strength Test

- Swales one-stage bond
  - After optical failure in thermal cycling
  - Visual inspection showed no evidence for air gaps, delamination, separation, peeling, etc.
  - Subjected to tensile strength test
    - Bond failed at ~280 N.
    - Bond failed at diode face, not at xtal face.
  - Bond strength is >25x requirement, even after it has degraded from excellent to poor optical contact.



Shear Strength Test

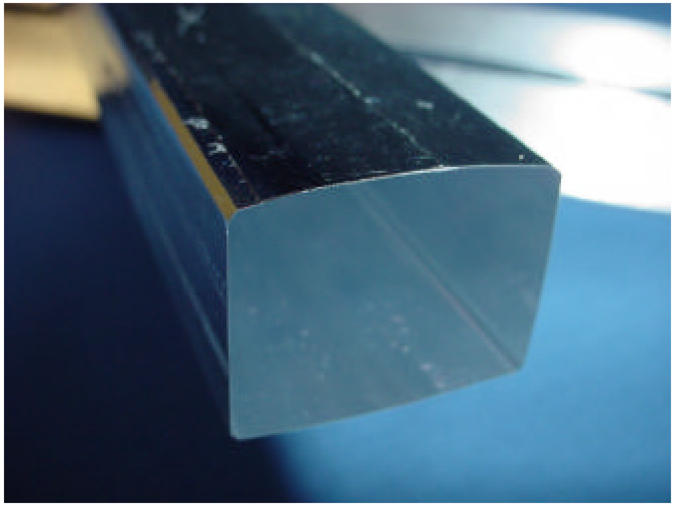


- ❑ **Swales one-stage bond**
  - – **Subjected to shear strength test**
    - **Bond failed at ~240 N.**
    - **Bond failed at diode face, not at xtal face.**
  - – **Failure occurs typically at >300 N**

CsI(Tl) crystals

- CsI(Tl) gives high light yield with PDs and good stopping power for EM showers
  - LAT CAL numerology
    - 1536 crystals, each 326 mm x 26.7 mm x 19.9 mm
    - ~1200 kg of CsI
  - Need to characterize each crystal: 100% inspection and test
    - Dimensionally: completed CDE must fit in cell
    - Optically: xtal must have good light yield and taper
- Procurement and testing are responsibility of GLAST Swedish Consortium
  - Institutions are Royal Institute of Technology (KTH), Stockholm University, and University of Kalmar
  - Responsibilities for crystal work:
    - Kalmar developed test benches and procedures
    - Kalmar and KTH test the crystals (mechanical / optical performance)
    - KTH tests boule samples (radiation harness test)
- Performance spec: LAT-DS-00820-03

Crystal Wrapper



- Wrapper must be highly reflective
  - 3M VM2000 specular film
    - Gives 20-30% more light than standard diffusive white wraps (e.g. Tyvek, Tetratex)
    - Stable, rigid material will not wet xtal surface as Teflon-based wraps can (e.g. Tetratex)
  - Easy to form with hot molding (Swales)
    - Form VM2000 around aluminum mandrel in xtal form (with chamfers)
    - No loss in light yield or mechanical stability from hot molding
- Molding is responsibility of Swales